Net-Centric Information and Knowledge Management and Dissemination for Data-to-Decision C2 Applications using Intelligent Agents and Service-Oriented Architectures

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***Abstract* – The Tactical Information Technologies for Assured Network Operations (TITAN) Program aims to achieve net-centric information and knowledge management and dissemination integrated with data-to-decision C2 Applications. TITAN is a multi-year effort to develop, demonstrate and mature information and knowledge (I&K) management and dissemination (M&D) services spanning multiple echelons and provide support to the network-centric operations process with collaborative military planning and execution monitoring. TITAN integrates heterogeneous, open-source intelligent agents and web services with network-centric communications infrastructures. These agents and services are designed to support users executing the Operations Process for command and control across command echelons from the brigade and below. The result is an adaptive system for collaborative battle command planning, execution and monitoring.**

In delivering TITAN, the team had to engineering novel solutions to several current research problems. These technical contributions include the development of a Battle Command-Warfighter (BCW) interface that integrates planning and situation awareness; definition of interoperability schemas for C2 information sources and services; management of distributed provenance; implementation of a network-centric message bus for communications across different network echelons and radios; and the development of agents and services to support Mission Command planning processes and numerous Data-to-Decision (D2D) threads in a comprehensive manner to execute TRADOC's Multi-Level Scenario. The integrated TITAN system has been demonstrated in numerous settings and will be featured at the Ft. Dix C4ISR "On the Move" in summer 2011.

I. INTRODUCTION

The Tactical Information Technologies for Assured Network Operations (TITAN) Program [1] is a multi-year effort to demonstrate and mature information management and dissemination (IM&D) services spanning multiple echelons in support of military planning and operations. Knowledge is embedded with applications as business rules provided by the services and intelligent agents as well as in the Tactics, Techniques and Procedures (TTP) of the users. The services augment existing tactical applications with I&K M&D capabilities that utilize available data, information and knowledge sources to make faster and better decisions while reducing the workload on the user.

This paper presents an overview of the TITAN system and describes some of the science and engineering challenges the team has addressed during the course of developing it. The foundation for TITAN is intelligent agents and web services integrated into a network-centric, service-oriented architecture. In this approach, "agents" are the software paradigm that provides the framework for designing, implementing, and analyzing a distributed collaborative system. Web services enable the description, registration, discovery, and consumption of services through standardized interfaces and protocols. Previous work in combining the agent and service paradigms, usually involve agents that implement services [2]. In TITAN, however, the team faced new challenges due to information heterogeneity and communication dynamics of network-centric tactical environments. In this setting, (1) heterogeneity and network dynamics impede reliable communications between agents and services; (2) representation, discovery, and interoperation of data and services in a consistent, concise, and efficient manner is difficult for agents to achieve automatically; and (3) standard methodologies for the test and evaluation of multiagent systems and network-centric systems do not exist.

TITAN integrated heterogeneous open-system, open-source intelligent agents [3][4][5] and web services which are actively involved with the user throughout the Operations Process [6] to initialize all relevant information products in a structured manner suitable for both automation and human interaction, with mixed initiative required for feedback and updates through collaborative planning and execution monitoring. The information elements (units, assets, environment, and control measures) are digitized and contextualized within facts nested within productized reports, orders and plans as articulated by doctrine [7][8]. Every persistent information or knowledge object is assigned a multipart information management key that supports versioning, filtering, fusion and transformations based upon provenance, and type. TITAN created a highly structured machine-readable human-compatible vocabulary for services involving both users and agents. The Battle Command (BC) domain provides the contents, and the BC product structure (e.g., header, paragraphs, annexes, etc.) provides the context.

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14. ABSTRACT
The Tactical Information Technologies for Assured Network Operations (TITAN) Program aims to achieve netcentric information and knowledge management and dissemination integrated with data-to-decision C2 Applications. TITAN is a multi-year effort to develop, demonstrate and mature information and knowledge (I&K) management and dissemination (M&D) services spanning multiple echelons and provide support to the network-centric operations process with collaborative military planning and execution monitoring. TITAN integrates heterogeneous, open-source intelligent agents and web services with network-centric communications infrastructures. These agents and services are designed to support users executing the Operations Process for command and control across command echelons from the brigade and below. The result is an adaptive system for collaborative battle command planning, execution and monitoring.

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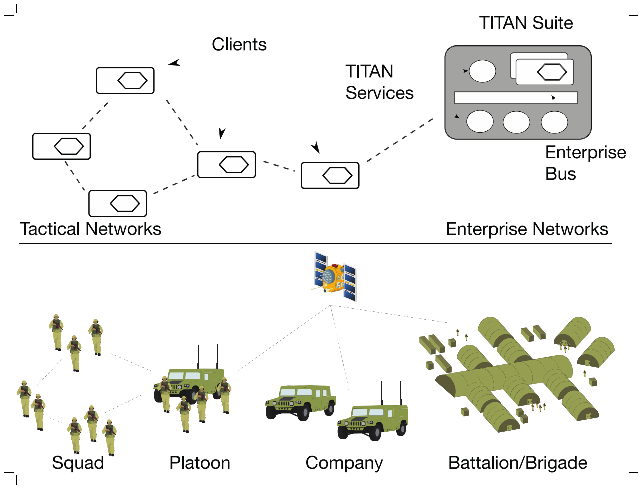

Figure 1. TITAN System Overlay and Operating Environment.

II. TITAN OVERVIEW

TITAN supports the Military Decision Making Process (MDMP) across military echelons. Specifically:

Mission planning and collaboration. In the MDMP a mission or plan begins with a commander in a command headquarters gathering data and intelligence from staff and issuing warning orders to lower-level units. During information gathering, the commander incorporates data and information sources (e.g., unit strength and readiness, terrain, enemy capabilities, etc.). This requires collaboration among command staff and lower echelons along with querying external data sources. Upon completion of planning, the orders are disseminated to the subordinate units to perform further refinements until the plan is ready to be executed.

Operations monitoring. Commanders monitor the situation from information flowing up from subordinate units and other sources. As the operation evolves, commanders collaborate between the echelons and issue updates and new orders. An alert, such as IED detection or ambush, is issued from individual dismount soldiers and sent up to their superior commanders. Alerts may necessitate a change in the plan and commanders will update subordinates accordingly. Events from external sources and higher echelons also get filtered down to lower echelons and may cause changes to plans.

Network-Centric C2. TITAN manages heterogeneous communications architectures and the information flows on the echelon structure and network environment. Orders and data generally flow from upper echelons (e.g., division, brigade, battalion) down to lower echelons (e.g., company, platoon, dismount), while situational awareness, alerts, and other requests flow up. Communications at the upper echelons is considered relatively static and stable while at lower echelons, a dismounted soldier's applications must handle intermittent connectivity, low data rates, and low power consumption.

Net-Centric I&K M&D. TITAN produced an XML schema for C2 Products (**prdC2**), including representations for plans, orders, and relevant reports. **prdC2** provides a single structure for agent-enabled BC services, enabling TITAN to maintain a common data blackboard. The TITAN Message Object Library (MOL) is a common API for information management and dissemination mechanism. Agents and services that use the MOL automatically interface to other TITAN-compliant agents and services, automating interoperability across heterogeneous agent frameworks and among agents and humans. Operational users are able to relate their work product (MDMP/BC/C2 product) semantically as well as contextually to the OPLANs, OPORDs, WARNOs and FRAGOs[1]. All M&D services are also capable of federating amongst each other to initialize, update, and provide feedback and assessments for finalizing certain work products, topics and/or facts. TITAN enables distributed, asynchronous execution of MDMP by providing permissions, preferences, maintenance and tracking of provenance and pedigree of information throughout the environment.

III. TITAN CONCEPT OF OPERATIONS

Fig 1 illustrates the TITAN system architecture, composed of a set of TITAN suites installed at every facility responsible for I&K M&D. The applications running on devices available to individual users and at lower echelons may be configured with a tailored subset of TITAN services that are clients to a given TITAN Suite, and the communications links between them. A TITAN Suite, as shown in Figure 2, is responsible for combining information from data sources, situational awareness, and interfaces to external services and distributing orders to lower echelons. At lower echelons, applications have limited bandwidth to receive orders, make requests, and send situational awareness and alerts to other users and units. TITAN services enable users to initiate, collaborate, and coordinate within a Tactical Operations Center or a lower echelon Command Post as well as horizontally and vertically across echelons and to monitor relevant execution events and activities in support of user information requirements (e.g., Commander Critical Information Requirements (CCIR)) all in accordance with the Operations Process.

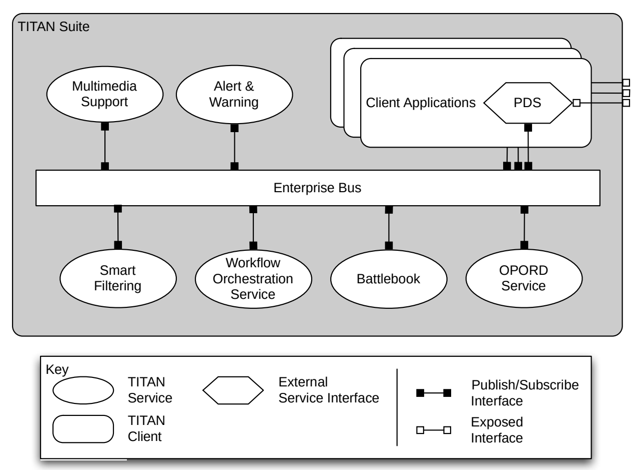

Figure 2. A TITAN Suite.

1 Operation Plans, Operations Orders, Warning Orders, and Fragmented Orders.

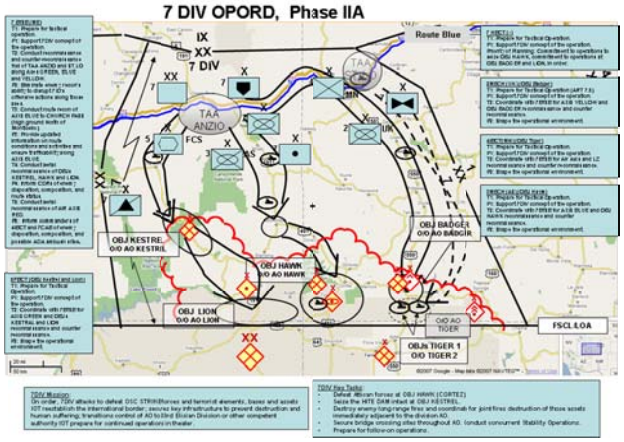

Figure 3. Sample OPORD Overlay with Text Annotation.

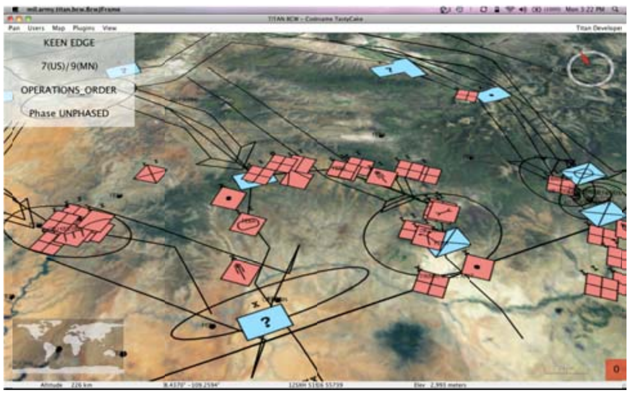

Figure 4. Geo-referenced Battlefield Objects in the BCW.

One of the challenging MDMP *operational processes* is the subordinate Troops Leading Procedure (TLP). The MDMP and TLP provide the commander and staff doctrinal guidance to facilitate their conduct of battle command responsibilities. This is part of a broader *operations process* consisting of the following activities: *planning*, *preparation*, *execution*, and *assessment*. For a given unit, a single short mission statement in the OPORD governs the *operations process*. The OPORD (Figure 3) is typically a document conveyed in Microsoft Word. *Planning* activities always precede *preparation* activities and *preparation* activities always precede *execution* of a mission. *Assessment* activities occur concurrently with the other three as a mechanism for establishing a closed-loop system. While the MDMP/TLP OPORD specifies the mission and tasks in plans and orders, commanders must not forget to provide integral I&K M&D support for Standing Operating Procedures (SOPs)---which can include the business rules associated with all implied tasks and can go a long way to facilitate and expedite the MDMP. Overall TITAN suites support the *operations processes* by contributing essential components to demonstrate future operational capabilities (FOCs) essential to activate and empower BC. Specifically:

1. Communicate reliably via robust networks that allow self-organization, self-healing, resource allocation/quality of service based upon mission requirements. TITAN's underlying message object library and message services enable the TITAN C2 applications to operate effectively across heterogeneous and dynamic network links.

2. Display relevant information sharable with all interoperable systems using standard geospatial foundations. TITAN's unified battle command warfighter interface (BCW) (Fig. 4) enables overlays of situation awareness, plans, orders and the organizational hierarchy.

3. Collaborate to achieve shared understanding and ensure unity of effort in both high and low bandwidths. Instances of TITAN BCW suites are situated at command posts across echelons. TITAN suites are federated to allow commanders to engage in collaborative planning, monitoring and execution.

4. Create, change and disseminate plans and orders to include attached graphics between command post, platforms, and leaders. The TITAN BCW provides tactical graphics and enables the commander to correlate information in the OPORD document with geo-referenced SA and operational data.

5. Maintain situational awareness to make timely and informed decisions during operations. TITAN includes bridges to the C2 Publish and Subscribe Server (PASS) and can exchange messages in formats (such as VMF) used by FBCB2 and CPoF.

6. Generate a *running estimate* by gathering and tracking information to support tactical decision-making. TITAN provides a continuous assessment of current and future operations, including conclusions and recommendations through the use of intelligent agents for monitoring, alerts and warnings, as well as workflow orchestration.

7. Interoperate to exchange relevant operational information with Joint, Interagency, Intergovernmental nongovernmental organizations, contractors and Multinational partners. TITAN includes interoperability hooks, such as ontology-driven translation, for rapid integration with other data sources and partner systems.

IV. TITAN TECHNICAL APPROACH

A. *Modeling the Operational Use Case*

I&K capabilities include collaboration, management, dissemination, and processing---capabilities that are dependent the ability to reference and retrieve information, creating information from data, sharing data with disparate systems, managing databases. The ultimate capability TITAN seeks is the development of knowledge, understanding information and managing risk which must be contextualized using the current situation and mission via the capabilities to develop information products, for visualization and assessments. A common designator as described above is used by all TITAN services to tag all managed objects. As shown in Figure 5, observations (O_i) from multiple, raw or informed sources is

provided by information-oriented A&U observers to provide authoritative conclusions and assessments to knowledge-oriented A&U assessors and deciders in the form of information products such as reports (R_i), estimates (E_x) and orders (A_z). Knowledge is often associated with algorithms, procedures and processes that operate on input data and information to generate more focused, relevant and often actionable information. In addition, as shown in Figure 5, observer knowledge takes into account the situation $\{S_v, S_v\}$ to contextualize observations and provide reports (e.g., spot reports, position reports) suitable for assessors. Contexts for sensors are equivalent to orientation and calibration. Assessor knowledge is used to filter, fuse and transform (FFT) the reports in the context of the current situation to provide meaning and impact as part of running estimate products (e.g., logistics, intelligence). Assessors **filter** the content in reports by a) setting thresholds, b) locating objects in space and time, c) estimating their size and role, d) removing false alarms. Assessors **fuse** contents by applying correlation, association, tracking and aggregation algorithms. Assessors also **transform** contents from various reports to support their estimates and predictions using appropriate map background and adapt to semantics required by the deciders. Finally decider knowledge is used to make recommendations and decisions for use in plans and orders. Note that in the process of contextualizing and productizing information and knowledge one must consider the mission (M_n) and situation (S_v) of others (e.g., higher HQ / peer units) as well as one's own mission (M_m) and situation (S_u) . This thread from data-to-decision (D2D) as shown in Figure 5 typically spans multiple echelons and is fundamental to command and control in support of battle command (BC) and mission command (MC) concepts of operations (CONOPS).

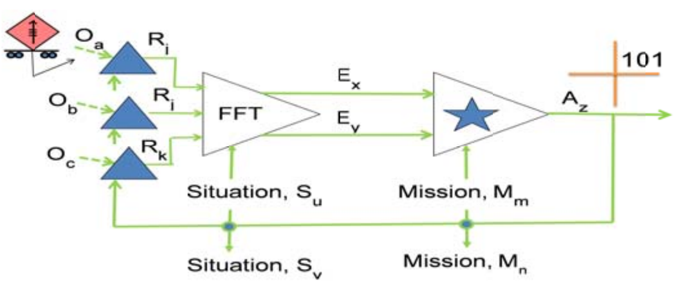

Figure 5. Information & Knowledge is Filtered, Fused, and Transformed into Mission Relevant Reports.

B. *The Battle Command Warfighter Interface (BCW)*

The TITAN System is a network-centric agent-based environment that spans the military hierarchy from TITAN Suites at the battalion and brigade command posts to dismounts equipped with mobile devices. A TITAN Suite consists of a set of TITAN services communicating over a communications bus and the Battle Command Warfighter Interface (BCW). The BCW exposes TITAN web services to the user via a map to provide a Common Operational Picture (COP) and widgets to provide planning and collaboration features. At lower echelons, limited applications running on mobile devices receive orders from upper echelons, providing situational awareness of other units, and send position/alert/request events to other units.

C. *TITAN Agents & Services*

Services provide capabilities to process and analyze data and support C2 operations; and are built with agent frameworks such as Cougaar[2] and Jade[3]. Some TITAN Services include:

- Order and Plan Support (OPS) maintains current draft orders synchronized with the COP. OPS is composed of several agents that perform tedious functions for the user, i.e., tracking unit course and speed, calculating areas of operations and aggregated centers of mass for units, and harmonizing fragmented orders with the original OPORD.
- Battle Book Support (BBS) queries the Table of Organization and Equipment (TOE), combat capabilities of units. Requesting services and agents pass the BBS a unit's identifier then receive the additional capabilities such as firing range, strength, and movement.
- Alert and Warning Support (AWS) enables the user to construct queries to be alerted about various threats such as IED explosions or enemy movements in an area of interest.
- The Smart Filtering Service (SFS) processes free-text such as recorded chat logs of staff soldiers to identify significant facts such as enemy movements.
- Workflow Orchestration Support (WOS) is responsible for web service composition. The WOS exposes TITAN data as a web service to external consumers, and exposes external web services to consumers inside the TITAN Suite.
- Multimedia Support (MMS) adds support for supplemental multimedia content (e.g., recorded voice, images, or video) to clarify/explain TITAN data or products.
- Initialization and Continuity of Operations (ICS) is responsible for processing new orders and maintaining synchronization among all TITAN services within a suite with respect to the current state of the user products, creating a draft order for a unit, and processing new orders.
- The Product Dissemination Support Service (PDS) is a decentralized message transport service that delivers TITAN messages between echelons and within a unit. The underlying transport mechanism for the PDS is a decentralized implementation of XMPP [9]. The PDS allows the system to handle dynamic network characteristics than either a purely centralized or a purely distributed approach.
- Battle Command Query Support (BQS) Service for synchronizing with ABCS, Joint and coalition C2 Data services (e.g., PASS, JC3IEDM, NFFI, C2core).
- Early Warning Support (EWS) Service for strategic alerts from the Joint Embedded Messaging System (JEMS).
- Collapse Collaboration Support (CCS) Service for enabling a collaborative two-way CPOF user Interface.
- Office Synchronization Support (OSS) Service for enabling a collaborative two-way Microsoft Office Interface.

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2 http://www.cougaar.org/

3 http://jade.tilab.com/

V. KEY TITAN ENGINEERING CHALLENGES

A. TITAN Evaluation Methodology

The TITAN evaluation methodology is based on software engineering approaches. The overall procedure is an extension of Roche's process of measurement [10], which includes six steps: selection, verification, instrumentation, collection, and evaluation. Use-case scenarios are extracted from system specifications. Goals are extracted from the use-case scenarios and the Goal Question Metric [11] approach derives quantifiable system-relevant metrics in the selection stage. The verification stage views the system from various perspectives (e.g., MAS, network-centric) and determines if the metrics comprehensively evaluate the system from these viewpoints. This stage also determines if cross-layer metrics (i.e. metrics that measure the interaction between the different "layers" in a system) exist. The instrumentation stage encodes mechanisms to collect metrics within the system. The collection stage gathers metric data through experimentation. Finally, the evaluation stage analyzes the results and determines if, and how well, the system meets its goals; if this is a comparison study, determine which system outperforms the other.

B. Network-Centric Emulation & Evaluation Testbed

Performing live field trials is expensive and time consuming; in addition it is hard to get repeatable scientific experiments. To address this, the team developed an experimental testbed to test, and analyze network-centric C2 systems that provides the realism, parameterization, and scalability required for deployment. Although there has been previous work in benchmarking agent frameworks, MASs [13][14], and distributed systems [15], this research does not address the these challenges or only examines these problems from a narrow perspective.

To augment field trials at Ft. Dix and Ft. Leavenworth, the TITAN team developed an experimental testbed for in-the-loop testing, referring to the direct execution of the software under test in a real-time, virtual emulation of comparable scale and complexity to the intended deployment. The Common Open Research Emulator (CORE) is the emulation testbed software for TITAN. CORE emulates wired and wireless network connections, supports live network connections, visualizes network topology through a GUI, and can distribute emulation across multiple hosts. These features allow for a scalable, automated, real-time emulated testbed solution. Comprehensive testing includes four types of emulation: (1) Human-in-the loop, where operators and SMEs observe and interact an emulated network; (2) Software-in-the-loop, with the TITAN suite installed within virtual nodes; (3) Hardware-in-the-loop, by installing TITAN on a prototype radio interacting with an emulated network of digital replicas; and (4) Internet-in-the-loop in which the wider IP cloud is visible to the virtual subnets for a broader range of test scenarios. We believe that TITAN is the first Army R&D program to undergo both live and emulated evaluation studies.

C. Integration of Net-Centric of Agents and Web Services

Previous work combining agent-based computing and web services shows the basic premise based on the definition "agent" and the role of web services [12], [11]. While serving as a foundation for agent functionality, the web service, and their basic interaction patterns, past work does not take into account the network communications dynamics of the operating agent. Past work assumes that communications channels remain static. However, in TITAN, agents and web services have specific interaction patterns dependent on network, command and information hierarchies.

TITAN's network hierarchy, structure, and information data flows are closely coupled to the military echelon. The networks at upper echelons have relatively static configurations with higher bandwidth and low latency while nodes at lower echelons have to tolerate volatile network connectivity, low bandwidth, and latency issues. Given the dynamic nature of these heterogeneous networks, agents at all echelons must be aware of disruptions to communication and network dynamics

D. Interoperability Challenges

TITAN provides the middleware to accommodate existing C2 products as well as provide an open vehicle for integrating additional business rules as new agents and services. As such, TITAN is designed to manage different (and often competing) standards and specifications that must coexist due to existing systems from Army PMs, Joint Programs and coalition partners. Rather than forcing everyone to comply with a given standard, TITAN supports more forward looking flexible representations mediation and harmonization of multiple representations. For example, display standards such as MIL-STD-2525c, APP6(A), have different symbol codes for the same tactical objects. Information Exchange Standards (e.g., JC3IEDM) may have different representations for battlefield geometries (e.g., axis of advance) than MIL-STD-2525c. Internally TITAN maintains unique representation for each distinct type of battlefield object. Externally, TITAN supports mappings to non-TITAN interfaces promoting maximum interoperability. TITAN has been used to mediate across disparate implementations that use common standards.

E. Distributed Intialization & Information Provenance

Automated and dynamic initialization is central to many I&K M&D issues. TITAN employs a persistent and globally unique structured five-part designator (dsg) for each item that requires I&K M&D. While other systems may use a globally unique identifier key, the TITAN dsg also enables persistence across many operations, quick access, filtering, fusion, translation (FFT) and sorting of similar types of objects or of objects within the same hierarchy. In addition, information about the provenance [17]. of each item is built-in to the dsg rather than added as an afterthought.

F. Representation, Discovery, and Interoperation

The representation of intelligent agents and web service components is vital for successful discovery, composition and interoperation. TITAN agents at each echelon require services to include semantic descriptors such as unit designation (e.g., brigade, battalion) and unit role (e.g., infantry, combat support, medical support) to support addressing in information flows.

VI. DISCUSSION

This paper provided an overview of TITAN, a U.S. Army initiative to create a net-centric battle command automation and interoperability framework based on integration of intelligent agents with existing C2 systems and data sources via web services in a service-oriented architecture. In doing so, the TITAN R&D team addressed a number science and engineering challenges. We emphasize three key contributions.

First, TITAN integrated agents and services [4] to provide adaptive, autonomous support to commanders via software that is aware of the user focus and needs. TITAN services maintain the context and pedigree of the information that is created or reused where appropriate. The TITAN BCW supports these services enabling the user to create a plan, collaborate with other users, and on a product as well as provides a run-time environment for the agents. In this way, TITAN exhibits multiple agent-service interaction paradigms.

Second, from a data and representation standpoint, TITAN developed a flexible referencing scheme in which information need only be created or entered once; avoiding confusion with duplicates, and will facilitate correlation and merging of information entered by other users as required. TITAN software agents and services provide the content for review instantly in the proper location and the proper format for update or feedback. This capability alone has the potential to speed up the MDMP/TLP to provide more time for subordinate units to execute a mission in accordance with the 4/5 rather than the 2/3 planning/execution time-ratio rule.

Lastly, the TITAN team developed a comprehensive test and evaluation strategy that combined field trials with software-in-the-loop emulation. TITAN established an architecture based on the multi-echelon infrastructure available at Fort Dix for C4ISR and Network Modernization. The Host Infrastructure is made up of an available balanced mix of components and systems which is representative of the extent of horizontal (Peer Units) and vertical (Multi-Echelon) integration required by the MLS1 scenario as may be currently implemented and supported by Army PEOs with Army Battle Command Systems (ABCS) Programs of Record (PORs) at Technology Readiness Levels (TRL) 6/7.

Technology transition is a key goal for TITAN as I&K M&D is a well known gap for the current force. The TITAN strategy is to support a three tier architecture grounded in annual demonstration of cumulatively increasing capabilities. The bottom tier consists of the current force technology and infrastructure. The middle tier consists of TITAN services and intelligent agents and components from other maturing ATOs that are at TRL6. The top tier consists of new and evolving technologies providing Technology Objective Elements (TOEs) that are at TRL 3/4/5 and nominated by R&D managers for inclusion based on the D2D capability and technology roadmaps that facilitate maturation via D2D-wide experimentation culminating in an integrated Technology-enabled capability Demonstration (TCD).

Future Work. TITAN and other R&D programs provide the key Integration Framework that is distributed and made available to developers of new and evolving technologies to support their needs to augment and enhance interoperability and capabilities of Programs of Record (PORs). Framework Components (FWCs), by definition, have not yet transitioned but are bridges, middleware, verification, stimulation and integration test tools and/or user interfaces that fill a transition gaps essential to integrate newer technologies as part of annual Coalition-enabled D2D integrated Technology-enabled Capability Demonstrations (CTD). The team will be implementing a number of these future capabilities, focusing on knowledge technologies addressing: semantic web service descriptions, business rules for information flow, formal representations for provenance, and capturing more formal models of commander's intent. We believe richer semantic descriptions will enable increased autonomy greater support for the commanders who will be using the products of TITAN.

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